FAR-INFRARED AND SUBMILLIMETER FILTERS

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ABSTRACT

Filters are critical for thermal detector systems, which are responsive to a wide frequency range. Without spectral limitation the detectors respond to frequencies outside those of interest with the consequence of increased photon noise and detector loading. For cooled systems it is also important to filter out high frequency radiation, minimising the thermal load and cooling power necessary. At Cardiff University we are developing far-infrared and submillimeter bandpass, high-pass, and low-pass blocking filters using a metal mesh technology. We have been able to maintain high in-band transmission with good out of band rejection to UV wavelengths. This technology is space qualified and has been used in a number of Astronomical and Earth Observation projects. Here we present our latest advancements.

INTRODUCTION

Polymer film supported air-gap metal mesh filters have been under development in this group for more than 25 years and are in use in many instruments and observatories for frequency selection and thermal control. These devices show good rejection outside the pass band with high transmission in band. Their performance is not subject to drift after regular cryogenic cycling and they are able to withstand vibration at 30g while cold, so achieving space qualification. High-pass, low-pass, broad and narrow band-pass and band stop characteristics can be all achieved.

These devices however have some drawbacks, which could be improved. They are sensitive to poor handling, solvents and are easily damaged beyond recovery. The steel mounting rings can limit the packing density of a detector array and increase the load on the cooling system. The U.V. resistance could be better. Though never noted as a problem, the grids are free to vibrate independently and possibly introduce microphonic pickup especially with closed cycle coolers. They have significantly varying characteristics dependent on beam angle and should ideally be only used with nearly collimated beams. They require individual assembly making closely matched sets difficult to achieve.

These problems have been solved by using a solid polymer self-supporting filter without cavities. The filters are extremely durable and immune to all normal solvents. No mounting rings are required so array packing density is limited by the packing of cone and detector blocks. The thermal load of the devices is also considerably reduced. The U.V. sensitivity of the air-gap filters is due to the use of 1.5um P.E.T. as the grid support medium whereas the solid polymer d*evices involve greater thickness of polymer. In this solid assembly, vibrations will cause all the grids to move in step and will not affect the filter characteristic. The use of a solid polymer will cause refraction of the beam towards the normal and reduce spectral problems caused by highly off-axis rays. These filters are made as a sheet of material with good uniformity across the sheet. The sheet can then be cut up to give a batch of closely matched devices or be used as a single large filter for an entire array. These filters now replace the air-gap models in most applications.

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MANUFACTURE

The solid polymer filters are assembled as a stack of polypropylene sheets of accurately known thickness, some of which have photolithographically formed thin copper grids on them. This stack is placed in a precision platen press and is heated in a vacuum oven until equilibrium is reached. The vacuum oven is required to prevent entrapment of air and degradation of the polymer. The assembly is allowed to cool and then the filter is removed ready for a wide range of machining according to the application. The same general designs of grids as for air-gap filters are used though the actual recipes have to be changed due to the change of the refractive index between the grids. The tolerance of the grid spacing can be controlled to of the order of 0.1um, this is confirmed by the agreement between the model and the manufactured device. Filters can be made by this method with edges within better than 1% of the design. Reliable manufacture requires very close control of parameters.

PERFORMANCE MEASUREMENT

All devices are characterised using an evacuated Martin Puplett Fourier transform spectrometer. The instrument has a spectral resolution of 0.0625 cm^{-1} but the sampling beam is converging rapidly at F/3 so the observed sharpness of filter edges may be reduced. Figure 1 shows the typical characteristics for an edge filter.

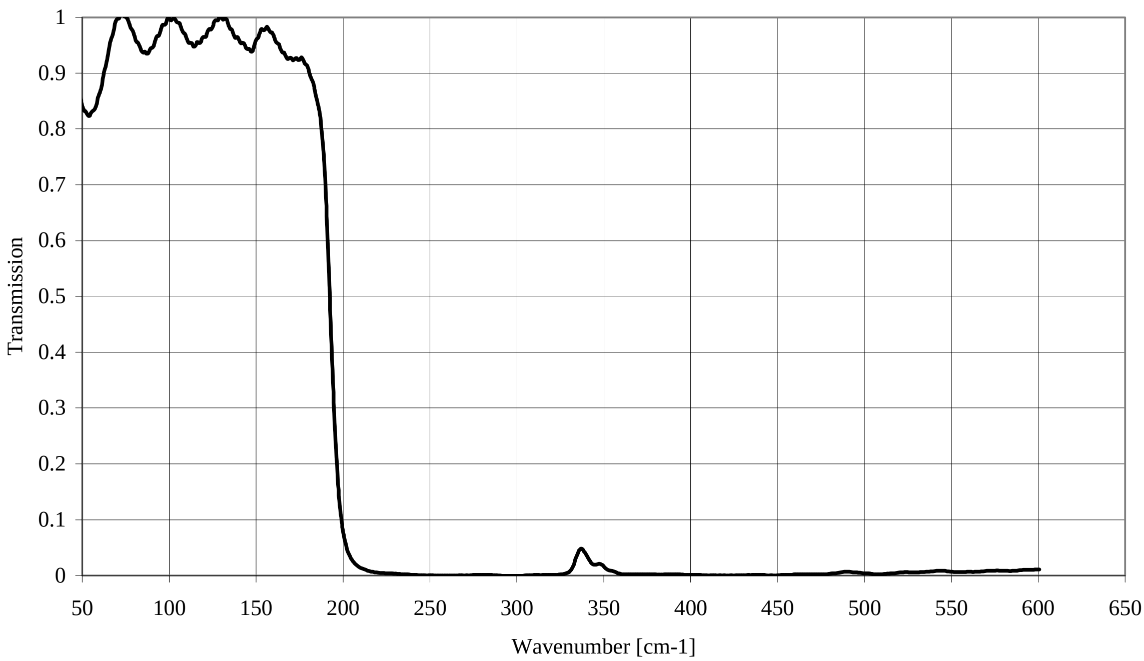

Figure 1: *Transmission spectrum of 50 cm^{-1} solid polymer edge filter.*

Detector systems usually employ several filters in succession in order to manage thermal loading. Harmonic leaks at multiples of an edge frequency are characteristic of grid filters and are removed by ensuring that the leaks in successive filters do not coincide.

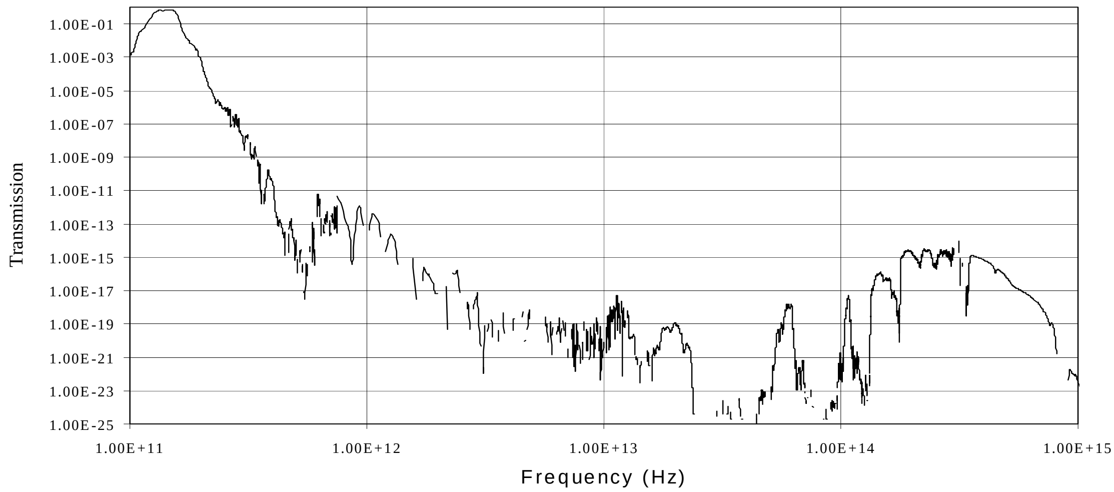

Figure 2: *Transmission spectrum of a series of solid polymer edge filters with one bandpass filter.*

THEORETICAL COMPARISON

All designs are produced by computer model, which can accurately predict the behaviour of the filters prior to manufacture. The computer program is based on a model[(1)(2)] where the grids correspond to lumped discreet electrical elements spaced on a transmission line. The discreet element values depend on the metallic grid geometric factors, which are modified by the optical properties of the polymer matrix. The distribution on the transmission line corresponds to the optical spacing between the grids. The polymer and metal may also modify the transmission due to absorption especially if they are in a resonant field. This model has been found to predict useful designs between 3cm^{-1} and 675cm^{-1}.

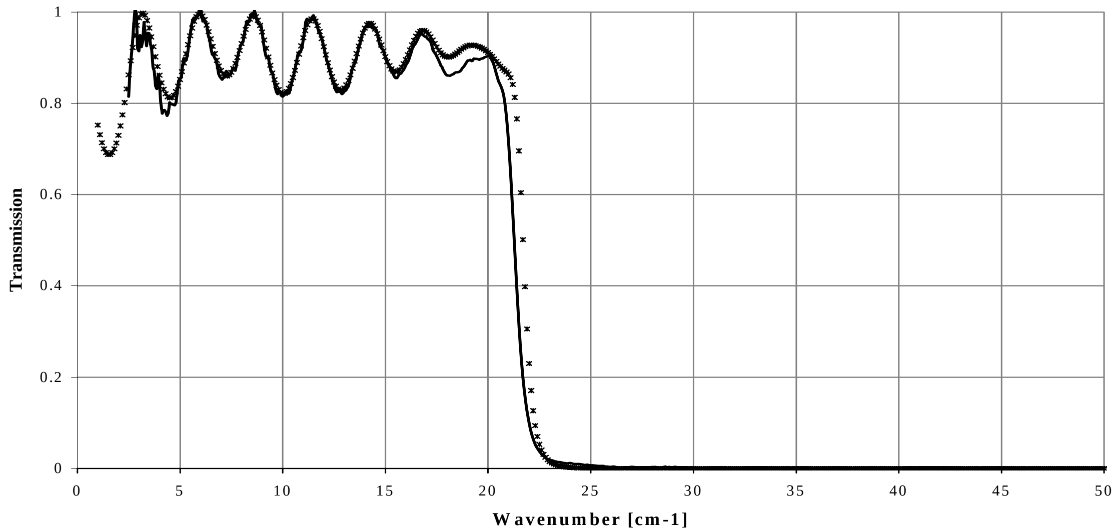

Figure 3: *Transmission spectrum of 22 cm^{-1} solid polymer edge filter and model.*

SOLID DIELECTRIC AND AIR-GAP FILTER COMPARISON

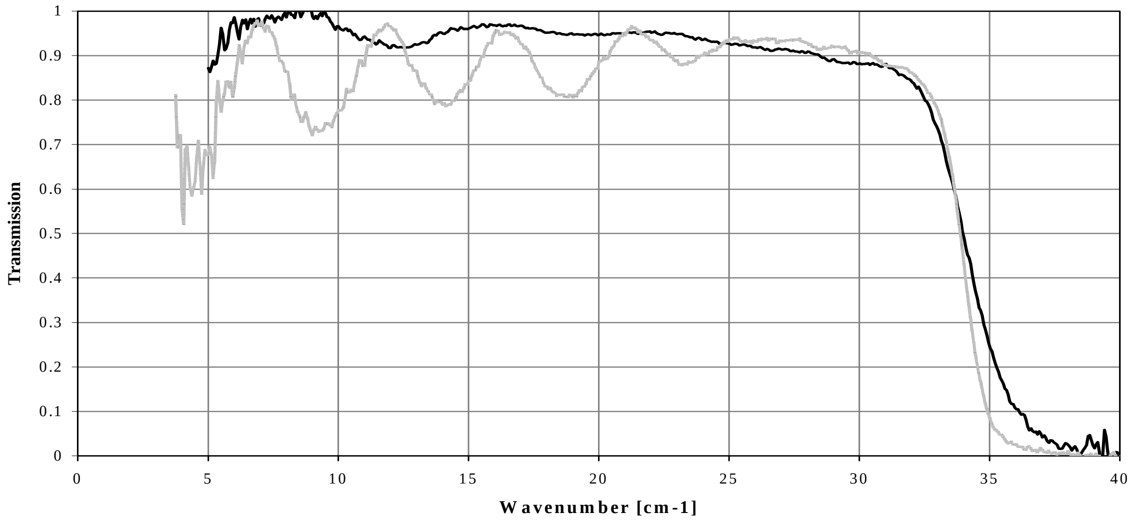

Figure 4: *Transmission spectrum of 34 cm^{-1} solid polymer edge filter and air-gap filter.*

Figure 4 shows that while the transmission band for the air gap filter reaches almost 100% that for the solid polymer is degraded by thickness fringing. This is not a problem for narrow band systems as design changes can move a fringe peak to coincide with the band. For broader band systems at wavelengths greater than 200um, a quarter wavelength 50% porosity P.T.F.E. (R.I.=1.2) layer has been found to be a suitable antireflection coating. This can be bonded to both surfaces of a filter using a similar technique to the filter manufacture. This coating has however been found to absorb short wavelength radiation and warm the filter leading to thermal emission. This problem was solved by producing an additional very thin thermal blocking solid grid filter which prevented the heating without reintroducing thickness fringing.

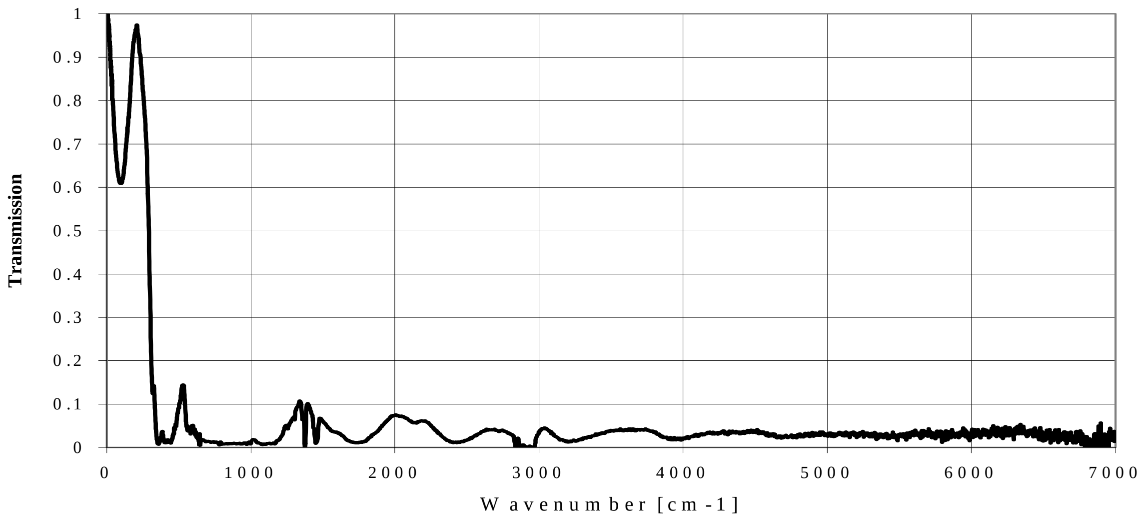

Figure 5: *High frequency transmission spectrum of thermal blocking solid polymer grid filter.*

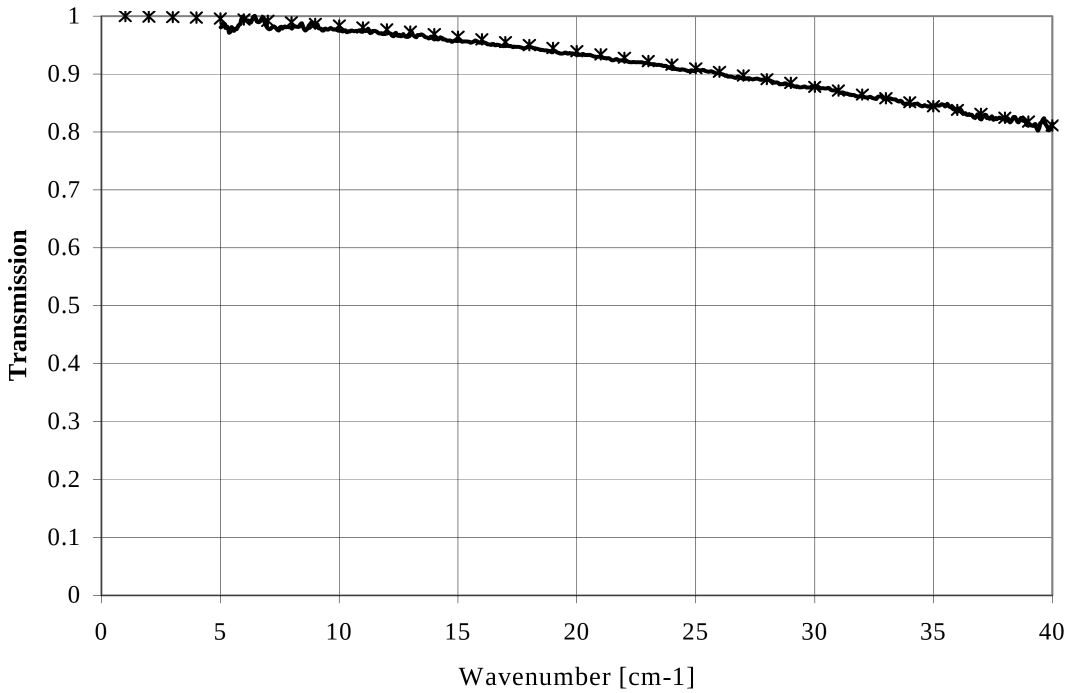

Figure 6: *Low frequency transmission spectrum of thermal blocking solid polymer grid filter.*

CONCLUSIONS

Grids embedded in solid polymer as filters can rival the performance of cavity spaced versions. The model program is sufficiently general to be able to model the solid filters. The advantages of the solid versions have led to them now replacing the cavity versions in most applications. Progress is being made towards larger diameters in order to fulfil the future needs of array detection systems. The lower frequency limit of this technology is probably set by the increasing device size in that limit though $1cm^{-1}$ may be achievable. To extend the upper frequency limit may require a change of matrix in order to avoid absorptions in the polymer, also the scale of the lithography will become submicron and require a change of technique.

REFERENCES

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2. N. Marcuvitz: *Waveguide Handbook*, Radiation Laboratory Series, McGraw-Hill Book Company, USA, 1951.